

SOLDER ON A SLOPED SURFACE

1 BACKGROUND

2 Solder is a material that typically contains tin and lead and that is commonly used
3 during the manufacturing of electronic circuit boards. Solder generally has a lower
4 melting temperature than the metals that may be included, as lines or layers, in the circuit
5 boards. Hence, once two or more metal lines or layers have been formed in a circuit
6 board, solder may be used to form an electrical contact between the layers and/or lines.

7 FIGURES 1A - 1E show cross-sections of semiconductor device structures after
8 various steps of a process for depositing solder on a planar semiconductor substrate
9 surface have been performed according to the related art. FIGURE 1A is a cross-
10 sectional view of a semiconductor substrate 100, such as silicon or gallium arsenide, and
11 of an organic film 110, such as a photoresist film, that has been deposited on the
12 semiconductor substrate 100. The organic film 110, according to the related art, is
13 typically spun onto the substrate 100 and is typically in contact with the entire surface of
14 the semiconductor substrate 100.

15 FIGURE 1B is a cross-sectional view of the layers 100, 110 discussed above after
16 the organic film 110 has been selectively etched to form a series of holes 120 (or
17 channels, troughs, grooves, or openings) above the substrate 100. The holes 120 in the
18 organic film 110 may be formed via photo-lithography or by any other process known in
19 the art of semiconductor device manufacturing.

20 FIGURE 1C is a cross-sectional view of the substrate 100 and organic film 110
21 discussed above after the holes 120 in the organic film 110 have been filled, at least
22 partially, with solder paste 130. Solder paste, in general, typically includes an admixture
23 of flux and solder particles. The solder paste 130 shown in FIGURE 1C may be
24 deposited in the holes 120 by any process known in the art. For example, a process
25 similar to the stencil printing process used in the surface mount assembly process can be
26 used. Specifically, a squeegee can be used to "roll" a bead of solder paste 130 across the
27 organic film 110 to deposit the solder paste 130 into the holes 120.

28 FIGURE 1D is a cross-sectional view of the substrate 100 after the solder paste
29 130 has been heat-treated to form solder bumps 140 on the substrate 100. In order to
30 form the solder bumps 140, the temperature of the solder paste 130 that had been in the
31 holes 120 of the organic film 110 was raised. The higher temperature caused the flux
32 portion that had been in the paste 130 to liquefy and activate the metal surfaces and

1 caused the solder particles in the paste to melt. In the molten phase, the solder will wet to
2 a solderable pad on the substrate surface while the surface tension of the liquid solder will
3 cause the molten solder to form the shape of the solder bump. Upon cooling of the
4 melted solder particles, solid solder bumps 140 were formed. Typically, the temperature
5 of the solder paste 130 is raised by the use of an oven or hot plate.

6 FIGURE 1E is a cross-sectional view of the substrate 100 and the solder bumps
7 140 after the organic film 110 has been removed. The organic film 110 may be removed
8 by any process that known in the art. Upon removal of the organic film 110, the substrate
9 100 may have additional structures, such as metal layers and metal lines, deposited
10 thereon, and the solder bumps 140 can be used to electrically connect two or more metal
11 layers or lines.

12 SUMMARY

13 A method of depositing solder, the method including the steps of providing a
14 substrate that includes a substantially planar surface and a sloped surface adjacent to the
15 substantially planar surface, forming a wettable layer on a portion of the sloped surface,
16 and forming a solder layer on a first portion of the wettable layer.

17 A semiconductor device including a substrate having a substantially planar surface
18 and an interior sloped surface, a wettable layer adhered to a portion of the interior sloped
19 surface, and a solder layer adhered to a first portion of the wettable layer.

20 DESCRIPTION OF THE DRAWINGS

21 The detailed description will refer to the following drawings, wherein like
22 numerals refer to like elements, and wherein:

23 FIGURES 1A-E show the steps of a process for depositing solder on a planar
24 surface according to the related art; and

25 FIGURES 2A-I illustrate steps of a process for depositing solder on a sloped
26 surface.

27 DETAILED DESCRIPTION

28 The following detailed description is presented to enable any person skilled in the
29 art to make and use devices that include solder. For purposes of explanation, specific
30 nomenclature is set forth to provide a thorough understanding of making and using such
31 devices. However, it will be apparent to one skilled in the art that these specific details
32 are not required to make and use the devices. Descriptions of specific applications are
33 provided only as representative examples. Various modifications will be readily apparent
34 to one skilled in the art, and the general principles defined herein may be applied to other

1 embodiments and applications without departing from the spirit and scope of the methods
2 and devices described herein. The methods and devices are not intended to be limited to
3 the embodiments shown, but are to be accorded the widest possible scope consistent with
4 the principles and features disclosed herein.

5 Historically, solder bumps have been deposited exclusively on substantially planar
6 surfaces, such as the surface of the substrate 100 shown in FIGURES 1A-E and discussed
7 in detail above. However, solder bumps have generally not been deposited on sloped
8 surfaces. Since semiconductor devices typically include both substantially planar and
9 sloped surfaces, the need exists for methods to deposit solder on sloped (*i.e.*, non-planar)
10 surfaces. FIGURES 2A-I illustrate various embodiments of methods of depositing solder
11 and solder bumps on sloped surfaces.

12 With reference now to FIGURE 2A of the Drawings, there is illustrated a cross-
13 sectional view of a substrate 200 that includes two substantially planar surfaces 210 and
14 two sloped surfaces 220. In some cases, the two sloped surfaces 220 may be on opposite
15 sides of the same square hole or rectangular channel formed in the substrate 200, as is
16 well understood in the art. As shown, each of the sloped surfaces 220 may be positioned
17 adjacent to a substantially planar surface 210 of the substrate 200. The slope of the
18 sloped surfaces 220 relative to the planar surface 210 may be at any angle greater than 0°
19 and less than 90°, measured relative to a line extending horizontally from the planar
20 surface 210. However, the 5°, 10°, 20°, 30°, 45°, 60°, 70°, and 80° angles, plus or minus
21 2.5°, are preferred in certain embodiments.

22 The sloped surfaces 220 may be formed by etching the substrate 200. The etching
23 step that forms the sloped surfaces 220 may include anisotropically etching completely
24 through the substrate 200 to form a hole. Alternately, the etching step may form a
25 channel in the substrate 200 and/or may not etch completely through the substrate 200.

26 FIGURE 2B is a cross-sectional view of the substrate 200 shown in FIGURE 2A
27 and of a wettable layer 230 that has been formed on a portion of one of the sloped
28 surfaces 220 of the substrate 200. The wettable layer 230 may include a metal that is
29 wetable by solder (*i.e.*, a metal on which solder can spread evenly, as opposed to beading
30 up on). The wettable layer 230 may be formed by any process known in the art including,
31 but not limited to, evaporation, sputtering, and plasma deposition. Metals that may be
32 included in the wettable layer 230 include, but are not limited to, gold, silver, and copper.
33 Compounds that are solder-wettable may also be used.

1 As shown in FIGURE 2B, the wettable layer 230 may be formed partially on the
2 sloped surface 220 and partially on the planar surface 210 of the substrate 200. In this
3 case, the portion of the wettable layer 230 that is formed on the planar surface 210 of the
4 substrate 200 may be substantially planar. Alternately, the wettable layer 230 may be
5 deposited exclusively on the sloped surfaces 220. The benefits of forming a portion of
6 the wettable layer 230 on the planar surface 210 will become apparent from the
7 discussion below, as will the benefits of forming the wettable layer 230 exclusively on the
8 sloped surface 220.

9 FIGURE 2C is a cross-sectional view of the substrate 200 and wettable layer 230
10 discussed above, after a coating layer 240 has been formed on a portion of the wettable
11 layer 230 and of the substrate 200. The coating layer 240 may include one or more
12 dielectric materials that are not solder-wettable. Such materials include, but are not
13 limited to, oxides, polyimides and solder masks. The coating layer 240 may be formed by
14 any method known in the art and may be thought of as a mask for the wettable layer 230
15 during solder deposition, as will be seen below.

16 FIGURE 2D is a cross-sectional view of the structure shown in FIGURE 2C after
17 an organic film 250 or organic layer has been adhered to a portion of the substantially
18 planar surface 210 of the substrate 200. The organic film 250 or layer may or may not be
19 adhered to the wettable layer 230 or the coating layer 240, but may be in contact with
20 both the wettable layer 230 and the coating layer 240. According to certain embodiments
21 of the methods for solder-deposition discussed herein, the organic film 250 is not in
22 contact with the sloped surfaces 220 of the substrate 200. Rather, the organic film 250
23 forms a bridge over the sloped surfaces 220 and over any hole or cavity that has been
24 etched or otherwise formed in the substrate 200.

25 A convenient method for substantially preventing the organic film 250 from
26 adhering to or contacting the sloped surfaces 220 of the substrate 200 involves using a
27 rigid or semi-rigid and substantially planar sheet of material as the organic film 250. The
28 sheet may be adhered to the substantially planar surfaces 210 of the substrate 200 after
29 the wettable layer 230 and the coating layer 240 have been formed. Then, because of the
30 inherent rigidity of the substantially planar sheet, the organic film 250 will not dip into
31 the etched portion of the substrate 200 and will therefore not contact the sloped surfaces
32 220, as shown in FIGURE 2D.

33 No limitations are made on the materials that may be included in the organic film
34 250. However, polymers that can form thin sheets with enough rigidity to bridge the

1 etched portion of the substrate 200 are preferred. The organic film 250 may be fixed or
2 held in place relative to the substrate 200 via electrostatic forces, a chemical adhesive,
3 and/or mechanical forces. For example, the organic film 250 may be rolled out over the
4 substrate 200 or may be wrapped around the substrate 200 like plastic food wrap around a
5 plate.

6 FIGURE 2E is a cross-sectional view of the structure shown in FIGURE 2D after
7 a section of the organic film 250 has been removed, leaving an empty volume 255 above
8 portions of the wettable layer 230 and coating layer 240. The removed section of the
9 organic film 250 is divided into two portions to facilitate description. The first portion of
10 the removed section, designated by the reference numeral 256, is positioned above one of
11 the planar surfaces 210 of the substrate 200 and contacts a planar portion of the wettable
12 layer 230 before removal. In FIGURE 2D, the first portion 256 is supported from
13 underneath by the substrate 200, the wettable layer 230, and the coating layer 240. The
14 second portion of the removed section, designated by the reference numeral 257, is
15 positioned above the etched portion of the substrate 200 before removal and is not
16 supported by the substrate 200. Instead, the second portion 257 of the removed section is
17 bridging the etched portion of the substrate 200.

18 Subsequent to the removal of the second portion 257, as shown in FIGURE 2E,
19 the remaining organic film 250 retains its substantially planar shape and continues to
20 bridge across the etched portion of the substrate 200. In other words, the organic film 250
21 does not dip or droop into the etched portion of the substrate 200 and does not contact the
22 sloped surface 220. Hence, a gap 260 or unfilled space is formed between the organic
23 film 250 and the wettable layer 230. As shown in FIGURE 2E, the gap 260 is formed
24 adjacent to one of the sloped surfaces 220 of the substrate 200.

25 FIGURE 2F is a top view of the structure illustrated in FIGURE 2E. In this
26 embodiment, the removed section of the organic film 250, represented by the empty
27 volume 255, has a rectangular shape and a width that is slightly larger than the width of
28 the wettable layer 230 and the coating layer 240. Accordingly, the substrate 200 is
29 exposed on both sides of the wettable layer 230 and the coating layer 240.

30 FIGURE 2G is a cross-sectional view of the structure illustrated in FIGURES 2E
31 and 2F, after the empty volume 255 has been substantially filled with solder paste 270.
32 The solder paste 270 may be placed in the volume 255 by any means known in the art of
33 semiconductor device manufacturing and does not have to exactly fill the entire volume
34 255. Any solder paste that is deposited on the organic film 250 may, optionally, be

1 removed after the volume 255 has been substantially filled. Typically, the solder paste
2 270 is viscous enough and the gap 260 is small enough such that little or none of the
3 solder paste 270 flows through the gap 260 until the solder paste 270 is heated.

4 FIGURE 2H is a cross-sectional view of the structure shown in FIGURE 2G after
5 the solder paste 270 has been heated and processed to form a solder layer 280 on at least a
6 portion of the wettable layer 230. The solder layer 280 may be formed on a portion of or
7 all of the wettable layer 230 that is not covered by the coating layer 240. The solder layer
8 280 may be formed by thermally treating the solder paste 270 in such a way that the flux
9 in the paste 270 liquifies and activates the metal surfaces and the solder particles in the
10 paste melt together to form the denser solder layer 280. According to certain
11 embodiments of methods for depositing solder, the solder layer 280 may be formed by
12 heating the solder paste 270 to about 180°C or less, plus or minus approximately 5°C.
13 Although a solder layer 280 is shown in FIGURE 2G, solder bumps may also be formed
14 if more solder paste 270 is used, as is understood in the art.

15 FIGURE 2I is a cross-sectional view of the structure shown on the left-hand side
16 of FIGURE 2H after the organic film 250 has been removed. The organic film 250 may
17 be removed by any method known in the art such as, but not limited to, chemical
18 dissolution, heating, and application of mechanical force to cause de-lamination.

19 The structure shown in FIGURE 2I includes a substrate 200 having a substantially
20 planar surface 210 and an interior sloped surface 220. Also included is a wettable layer
21 230, which may include a metal, and that is adhered to a portion of the interior sloped
22 surface. According to alternate structures, the entire wettable layer 230 may be adhered
23 to the sloped surface 220, if desired.

24 Adhered to a portion of the wettable layer 230 is the solder layer 280. In FIGURE
25 2I, the solder layer 280 is positioned over both a portion of the sloped surface 220 and a
26 portion of the planar surface 210. However, according to alternate structures, the solder
27 layer 280 may be formed and/or positioned exclusively over all or a portion of the sloped
28 surface 220. When the wettable layer 230 is formed over a portion of the planar surface
29 210, the wettable layer may be used to provide an electrical contact to a line or layer
30 formed on the planar surface 210.

31 As illustrated in FIGURE 2I, a coating layer 240 adheres to a portion of the
32 wettable layer 230. The coating layer 240, during the manufacturing of the structure
33 shown in FIGURE 2I, can assist in preventing deposition of the solder layer 280 in
34 undesired locations by effectively masking the wettable layer 230. Once the solder layer

1 280 has been formed, the coating layer 240 may, optionally, be removed from the
2 structure to facilitate the formation of electrical connections to lines and/or layers on the
3 adjacent planar surface 210.

4 The coating layer 240 may include any material that is not wettable by solder (*i.e.*,
5 on which solder does not readily spread). For example, the coating layer 240 may include
6 a dielectric material or, more specifically, an oxide. The solder layer 280 may, among
7 other materials, include a tin-bismuth compound or a eutectic, tin-lead compound.
8 However, no particular restrictions are placed on the materials that may be used to build
9 the structure illustrated in FIGURE 2I.

10 While the aforementioned and illustrated methods for forming a solder on a sloped
11 surface have been described in connection with exemplary embodiments, those skilled in
12 the art will understand that many modifications in light of these teachings are possible,
13 and this application is intended to cover any variation thereof.